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# Soil Protection under High Buildings in Sofia After Revealing of Karsts Caverns in Clay

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# SOIL PROTECTION UNDER HIGH BUILDINGS IN SOFIA AFTER REVEALING OF KARSTS CAVERNS IN CLAY

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**ABSTRACT**

In 2006 many engineers run into a difficulty with very rarely phenomenon during the construction of high buildings in exactly determined area to East of Sofia. Large caverns have appeared unexpectedly in the clay on depth of 4÷7m, just under the fundaments. Their volume has been around 3 ÷ 4 $m^3$. There were mean one cavern per 60 $m^2$. Such caverns have revealed as in the time of foundation pit, as under the old buildings. It was found that this is the known from the literature suffusion in clay which is rarely phenomena.
The phenomenon has been investigated. It was found that 20 years ago the same problem had been actuated too for our specialists but the final decision has been impeded from the lower level of the technology for investigations. The information has not widespread and now it is forgotten yet.
In this report are presented analyses of soil conditions, characteristics of structures, the investigation methods, the technical decisions for soil protection etc.

## INTRODUCTION

During the last 5-6 years the construction in Bulgaria developed extremely fast and covered all large cities and many resorts. The high rate of development contributed to the penetration of many new technologies and modern mechanization. Parallel to this, many technical problems related to the foundation of buildings and equipment called the attention of specialists.

The capital Sofia is one of the places with the largest amount of construction in Bulgaria. It is located to the south of Stara Planina Mountain in a large field surrounded by mountains. In geological terms the field represents a complex, asymmetric tectonic depression. The surface consists of Quaternary and Pliocene accumulations: sand clays, dust clay, sands and gravels. Their total thickness exceeds 30m. The large Iskar River and many of its feeders cross the field. The underground waters are fed by the steep slopes of the surrounding mountains, and mostly by Vitosha Mountain, which immediately surrounds the city to the south. The average annual rainfalls in the region amount to 640 mm/$m^2$.

Bulgaria is part of the temperate-continental climate zone.

## I. DESCRIPTION OF THE CASE

As of the end of 2006 the excavation started for laying the foundations of four identical seven-storey buildings in the southeast part of the city of Sofia. When reaching the projected depth of 8 m and after leveling the bottom, the builders unexpectedly discovered a large cavern in the clay earth base. It is egg-shaped with diameters of about 3.50/2/2 m. The walls of the cavern have a thin crust of red-brownish color (Fig.5).

In order to prepare a precise geological picture and find the location of the caverns, additional electrotomographic surveys of the earth base were conducted in 2006, as well as an inspection of the region, references on the practice and the results of other construction projects. The following findings were made:

1. The caverns are located in the sand-clay Quaternary layer, which has a capacity of about 8 ÷ 9m. Under the clay there are the Quaternary sands and gravel.
2. According to the geological picture of Sofia, the Pliocene clays contain limestone kernels and concretion. The

hypothesis is that during the infiltration of the ground waters through the clay the carbonate minerals (limestone fragments) slowly melted and gravitationally were taken downwards to the sand-gravel base. It is possible that a secondary sedimentation took place in this base, and respectively calcification of the gravel, followed by a new formation of karst. That is why the geological map of Sofia mentions caverns in the Quaternary gravel.

3. The caverns have no definite orientation and size. Often they are of an average size of about 2/3/2 m or smaller and have irregular shapes. Their volume reaches about 5 ÷ 6 $m^3$, and on average they are located at a depth of about 4.50 m to 6.50 m under the terrain.

4. There is no visible thinning of the earth base around the caverns. However, the experiments indicated that the volume density at the bottom of the cavern is considerably lower than that in zones without caverns.

5. The geophysical (electrotomographic) surveys revealed that under the West projected building there are six areas, which were thought to contain caverns, and which are situated immediately below the level of the main plane or at a depth of about 1 m.

6. Under the East projected building there are four zones identified by a geophysical survey, where caverns are expected to be found. Two of the zones are shallow (up to 1 m under the site), just along the outline of the foundation. The other two zones are situated at about 2 m and 4 m under the site where there is transition to sands, and it is difficult to say whether they are caverns or sands, which "distort" the picture of the electric resistance of the area. As mentioned in item 3, these sands contain carbonate and are subject to chemical suffusion, although for a rather long period of time.

7. At the adjacent site, the caverns expected to be discovered according to the survey were not found. They were shallow and of a small size and were destroyed during the excavation.

8. The method of electrotomography provides information solely on the vertical planes of the surveyed profiles, but not on the space between them. The experience from the West site indicates that a considerable cavern (seventh) appeared in the strip with a width of 2.50 m between two of the studied profiles, however this was not mentioned in the survey.

9. The experience indicates that in the zones with no caverns the clay earth base has a sufficiently high supporting ability and high values of the deformation modules (there is no danger of large subsidence).

10. According to the geological and geophysical surveys the layers are almost horizontal.

11. A month after the construction of the foundation and basement of the building, a new cavern was found just along the outline of the foundation. It was not clearly depicted in the electrotomographic profiles. Its filling after the beginning of the construction causes a number of technological problems.

What makes an impression is the fact that the first cavern was found by the builders completely by chance. If we judge by the parameters of the project, there was a minimum probability to reach the caverns. The four new buildings should have an elevation of the foundation -4.00 m, i.e. they should have only one basement floor. Eventually we found out that all caverns are located exactly at a depth between 4m and 7m. The first cavern that was discovered was noticed at the very last moment, when the wheel of the excavator had not sunk too much.

## II. HISTORY DATES AND REFERENCES

After inquiries were made, it turned out that the caverns in this region had been known twenty and more years before, when the first construction started in the region. This phenomenon is recorded in the engineering-geologic map of Sofia prepared in 1986 under the name "Karst in Clay". The map mentions that the caverns are located exactly in the same region of the town where they were found in 2006. Unfortunately, this map has not been published because of the enormous political and economic changes in Bulgaria that started in 1989. During the same period the intention to conduct a geophysical survey in the region did not realize because of the lack of appropriate equipment.

Despite the fact that it is not that common, the phenomenon Karst in Clay is well known to science. Usually karst is characteristic for limestone and partly for plaster. Karst in Clay is a complex of the phenomena chemical and hydraulic suffusion, and karst in carbonate sand clays or marl. It is widespread in arid (dry) areas with limited vegetation. The shapes of the relief resemble underground canals.

## III. CARRIED OUT INVESTIGATIONS

The geophysical method of electro tomography was successfully applied for discovering all caverns under the construction site. The advantage of this modern method of high technology is in the permanent depiction of the surveyed profile, based on the specific electric resistance of the rocks.

When searching for caverns, the interpretation of the results obtained from the electrotomography depends on the coefficient of soil pores. When there are caverns in similar environments, the resistance measured at those places would be higher than the one that is typical for the studied lithological modification.

The measurements were taken at four sites (A, B, C and D – see *Fig.1*). Six profiles were made at each site, with distance between the canals $\Delta X$=1m.

The measurements were taken at 5 m distance between the electrodes. The registration was made with the help of **SYSCAL JUNIOR** apparatuses of the French company **IRIS Instruments Co**., equipped with autonomous multi-electrode system.

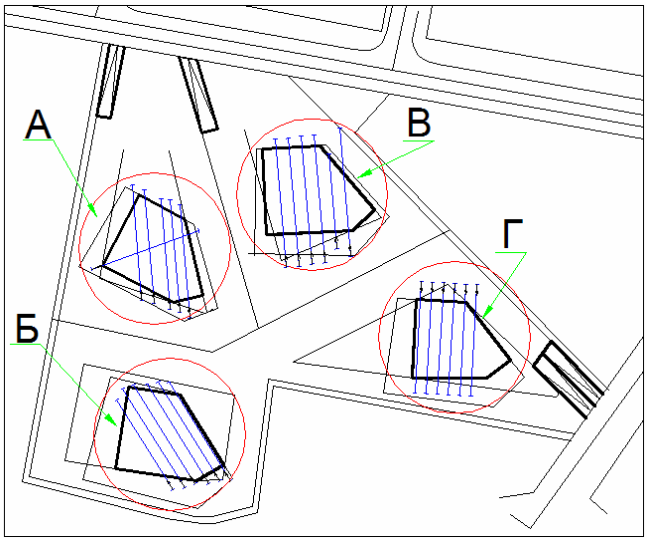



*Fig.1. Replasement of the profiles and foundation*

Fig.2 illustrates the applied 2-D measurement scheme with 16 electrodes.

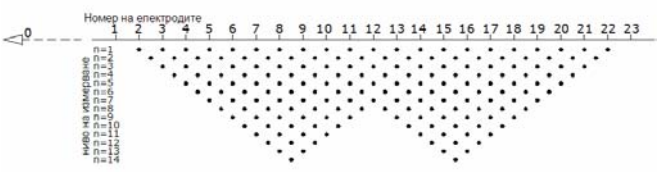


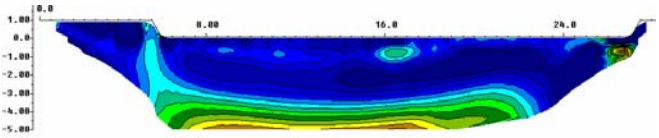

*Fig2. Scheme of the measurements trough the profile*

The results of the measurements have been processed with the help of the program **RES2DIN**, by means of which we have obtained the real distribution of the electric resistance of the geologic environment at a depth of up to 6 m and interval ΔX=1m.

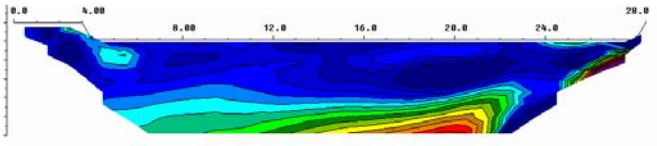
III.1. Place A

The results from the measurements, after being processed, are presented in *Fig.3*.

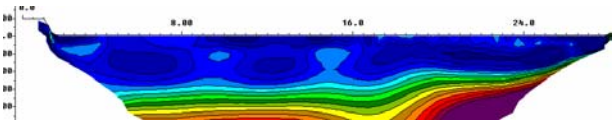
Profile 1



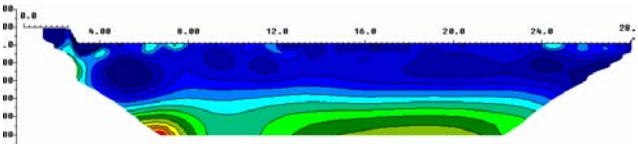
Profile 2



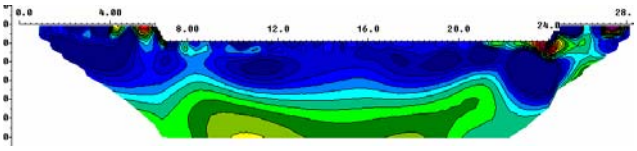
Profile 3



Profile 4



Profile 5



Profile 6

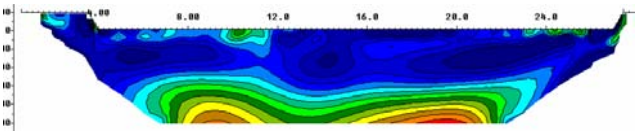


*Fig.3. Picture of the electrical resistance trough the profiles on the place A*

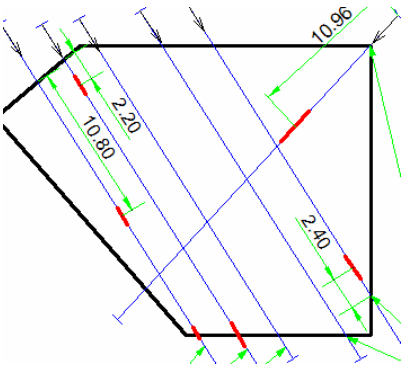



*Fig. 4. Situation of the high electrical resistance areas on the place A*

Out of the six electrotomographic profiles measured, for two profiles (*profiles 3 and 4 on Fig.3*) we do not observe zones (*numbered I through VI*) with higher resistance, which could be considered a breach of the earth base. The zones of potential breaches are marked in *Fig.4*.

The chemical analysis of the soil from the walls of the caverns indicates that there is $HCO_3$ – 410 mg/kg and pH – 6,72.

The values of the studied "in situ" physico-mechanical characteristics of the soil are summarized in Table 1:

Table 1: Physical -mechanical characteristics of the soil

| № | Characteristics | Dimension | Values |
|---|---|---|---|
| 1 | $\rho_n$ | kg/m$^3$ | 1,75 |
| 2 | $\rho_s$ | kg/m$^3$ | 2,71 |
| 3 | $\rho_d$ | kg/m$^3$ | 1,30 |
| 4 | n | - | 0.47 |
| 5 | Ip | % | 14 |
| 6 | Ic | - | 0,95 |
| 7 | φ | Deg. | 16 |
| 8 | c | kPa | 37 |

The fact that the caverns appear from a certain depth (4 m) (*Fig.5*) downward could be explained with several hypotheses:

- The more shallow caverns were destroyed a long time ago by heavy external loads. The deeper caverns have been preserved due to the dispersion of the normal strain and the vault effect;
- The upper 4 m accumulated during a later geological period when there was no penetration of carbonate admixtures;
- There were small caverns which were destroyed without noticing during the excavation works;
- The upper 2÷3m represent deposited earth masses which have stayed for more than 20 years and have acquired higher density.

*Fig.5. Photo of cavern*

We have not tried to prove or disprove the hypothesis made above. During construction it is always necessary to make deeper excavations, so the answer to the question would mostly have significance from an academic point of view.

## IV. TECHNICAL DESSISSIONS

The applied measures for reinforcement are subordinated to the need to create a homogeneous earth base in the fastest and most effective way. The following steps were undertaken (*Fig.6*):

1. We identified the places, which were indicated by the geophysic study as ones that might contain caverns.
2. The identified caverns were excavated completely, cleaned and filled with non-fractioned rock mass with a size of beans of 0 to 125 mm, with admixtures of clay and dust particles.
3. The rock mass was consolidated by layers of 30 cm
4. After the caverns were filled, the main plane of the future foundation was further consolidated by a vibration steam-roller (120 kN), which passed over the surface three times.
5. The outline of the site was carefully traced in order to detect subsidence and caverns.
6. On the site where the number of caverns turnout out to be larger (6 caverns on an area of 400m2), the one-meter contact layer of the base was replaced by an embankment of non-fractioned rock mass and consolidation with 12-ton vibration steam-roller by layers of 30 cm and 5 passings over each point.

Caverns were discovered in 2006 at other construction sites in the same region. Caverns have also been discovered under buildings with several floors already raised, which are endangered of bending. In some of these cases cement solution has been injected into the caverns. We do not consider it appropriate for the earth foundation to contain sections with such large contrast in the values of its deformation and strength characteristics, such as the difference between cement and sand clays.

## V. CONCLUSIONS

1. Karst in Clay is a rarely observed phenomenon. If it is not discovered during the period of survey and construction, it could turn into a serous threat of the general stability of the building or facility.
2. Thorough knowledge of and compliance with the general geologic conditions of the surveyed region and with

the larger scale geological maps is a mandatory prerequisite for avoiding dangerous omissions that have a random


*Fig.6. Filling of the cavern*

character at first sight, such as the Karst in Clay or other less common events.

3. The modern high-technology geophysic methods, electrotomography being one of them, offer the opportunity to detect soil anomalies during the stage of survey.
4. The filling of caverns with non-fractioned rock material with diameter of the beans from 0 to 125 mm allows a fast and efficient consolidation and restoration of the normal earth foundation with approximately identical deformation characteristics. The additional consolidation of the contact layer by a heavy vibration steam-roller is a factor for the approximate equalization of the characteristics. This would eliminate the possibility of existence of undiscovered caverns under the foundation.
5. When a preliminary survey has been conducted for discovering caverns, they can be filled with soil from the same excavation, with consolidation under a special project, which would aim at complete equalization of the characteristics of the foundation.

6. Where there are a large number of caverns at a given site, which suggests a heterogeneous earth base, a one-meter layer of the contact plane is replaced with a consolidated embankment of non-fractioned rock material in order to attain better homogeneity of the foundation.

7. Most often the complete replacement of the soil layer which contains caverns turns out to be an inefficient solution.